Requirements of Beam Dynamics on the Alignment of the Low-β Insertions

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Abstract

In the collision configuration, the low-β section concentrates most of the LHC complexity. The perturbation by the multipolar field components of the superconducting low-β quadrupoles is strongly enhanced by the large β-function and the crossing-angle beam separation; it requires fine correction. The aperture limit of the machine occurs in the same quadrupoles. The beam separation necessary to minimize the long-range (LR) beam-beam kicks reaches its minimum at the same place. Recent studies show that the nominal beam separation should be considered as a minimum requirement. The possible misalignments of the quadrupoles in the low-β section may therefore have more serious consequences than simple geometrical effects at the collision points. In addition to a loss of luminosity due to an imperfect beam overlap, the detector background may be enhanced by a displacement of the collision point and/or by any change of the trajectories inside the geometrical acceptance of the low-β section. The stability of the beam dynamics may be altered if the beam separation is reduced at the LR interaction points or if the balance between parasitic multipoles and their non-linear correctors would be broken. An imperfect overlap at the collision point may even reduce the beam lifetime. The problem is further complicated by the couplings: if, e.g. a quadrupole is rotated, a successful betatron coupling correction will not prevent the coupling of the crossing-angle separation to the other plane.Consequences can be an imperfect overlap at the IP, a perturbation of the LR effect, of the multipolar compensations, a leakage of the crossing-angle bump all around the machine in both planes. This long enumeration shows potential problems and the aim is to avoid them as far as possible at the design level and correct those which cannot be avoided.

To establish the requirements on the alignment of the low-β section, two steps are necessary. First, the allowed tolerance on the beam parameters which govern the performance must be identified. This is the aim of this study. In a second step, these tolerances can be used to set limits to the misalignments. This is not covered in this note.

The conclusions are as follows: The tolerances on the beam dynamics parameters are summarized in table 1. In many instances, the beam dynamics phenomena concerned are complex or not easilly predictable, like the background. These tolerances should therefore be regarded as guidelines which may have to be reconsidered would they be difficult and expensive to reach. On the other side, any gain in tolerance is likely to pay in terms of efficiency of commissioning and operating LHC. We summarize in Table 2 the tolerances on mechanical assembly and alignment considered so far to assess the geometrical aperture left for the beam.

Parameter		Tolerance	Comment
Loss of Luminosity	per source	2%	
	all sources combined	5%	
Beam overlap at IP		0.1σ	
β-beating at IP		4%	per plane
Dispersion at IP		3 cm	per plane
Absolute position of IP	transverse	1 mm	
	longitudinal	5.5 cm	
Relative position of IP	transverse	.1 mm	stability,reproducibility
Crossing angle		7μrad	
LR beam separation		16 LR's$\times$ -1σ	allowed reduction
Betatron coupling	$Q_I - Q_{II}$	0.05	before correction
		0.001	after correction
Tunes	drift	0.001	
Tunes	ripple	10^{-5}	per source
Closed orbit	leakage	$< \sigma/10$	
Dynamic aperture	at 10^5 turns	$< \sigma/4$	

Table 1: Tolerance on beam parameters

Parameter	Tolerance
Transverse pos. of cold bore	0.6 mm
Alignment of fiducials	1 mm

Table 2: Tolerance on mechanical aperture